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A Plasma Source with LaB_6 Hollow Cathode for a Diagnostic Beam Injector

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1. INTRODUCTION

The hydrogen neutral beams are widely used to diagnose the plasma in magnetic fusion devices. The beams are extracted from the plasma generated by a plasma source, accelerated to desired energy and subsequently neutralized in a gas target. The critically important characteristics of the plasma source are the composition and the source lifetime. A presence of the molecular ions in the plasma results in appearing of atoms in the beam with energies E, E/2, and E/3, where E is the determined by accelerating voltage (E=eU). For example, the plasma sources of the diagnostic injectors developed for TEXTOR and TCV tokamaks [1,2], which are based on RF-discharge, has a long enough lifetime (many thousands shots) for a pulse duration 2-10 sec. At the same time, the proton fraction in the RF-plasma is about only 60% by current [2,3].

The plasma produced in an arc-discharge plasma source generally has a higher proton fraction (80-90%) [4]. For the plasma source developed in Novosibirsk and its modifications [1,4], the plasma density near the anode hole is quite high, of the order of $10^{21}m^{-3}$ and electron temperature is ~5 eV. For these parameters, the gas puffed into the anode region is to be almost completely ionized and the molecular ions are dissociated. The plasma generated near the anode orifice expands towards the plasma grid and its density falls dawn to ~ $10^{18}m^{-3}$. Due to this density reduction, the additional gas ionization in the expansion volumes becomes negligible and additional molecular ions do not appear. This type of arc-discharge plasma source with a cold cathode is used in the neutral beam injectors with a pulse duration limited to ~0.5s or less [4]. The main disadvantage here is a limited lifetime of the plasma source parts due to their intensive erosion.

In this paper, a modification of the arc discharge plasma source is described, in a hollow cathode with internal LaB_6 electron emitter is used instead of the cold metal cathode. This plasma source is developed for a hydrogen beam diagnostic injector. It is expected that this plasma source has longer lifetime operating in a few second pulses and generates a plasma with lower molecular fraction compared to RF-based plasma source [2].

2. PLASMA SOURCE

2.1 General design

General layout of the plasma source is shown in Fig.1. It consists of an anode (3), gas-discharge channel (2), cathode assembly, magnetic coil (4), an array of permanent magnets (5) to transport the plasma flow to plasma grid and the cooling system. The gas-discharge is sustained between copper anode and a hollow cathode with internal LaB_6 electron emitter. The discharge channel is formed by a stuck of isolated metallic washers with internal diameter varying from 5 to7 mm. The plasma production is increased by application of a longitudinal magnetic field about 0.1 T in anode region, which is formed by the coil (4). The gas (hydrogen) is supplied through the gap between the anode and the nearest washer, and into the cathode chamber. The washers, cathode and anode have intensive water cooling.

The beam is extracted and accelerated by a four-electrode ion-optical system (6) with 163 holes each of 4mm in diameter. The diameter of plasma emitter at plasma grid is about 70mm to provide 2 A ion beam current.

2.2 Multipole peripheral magnetic field

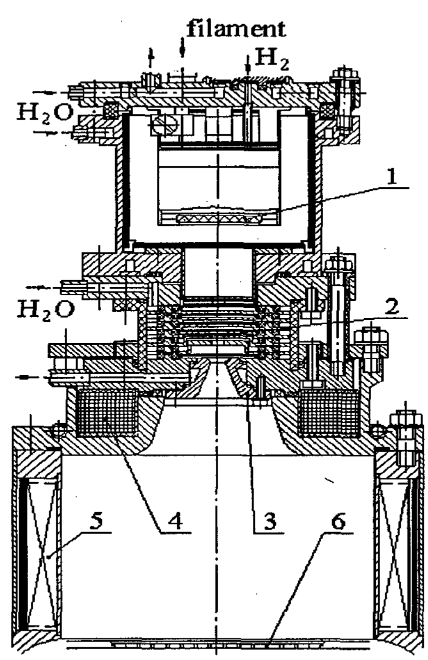

Fig.1. The plasma source with hollow LaB_6 cathode. 1- LaB_6 tablet, 2- discharge channel, 3- anode, 4 – magnetic coil, 5 – permanent magnets, 6 – electrode of acceleration system.

To obtain the required current density of a plasma emitter of 0.1-0.2 A/cm^2 the high density plasma jet expands from the anode of the plasma source into a cylindrical volume with peripheral magnetic field. The field is formed by an array of 16 permanent magnets, which provides magnetic picket fence configuration near the wall. The $Nd_{15}Fe_{77}B_8$ permanent magnets have 80 mm length and 9x12 mm cross-section. Magnetic field strength at inner wall of the expander is 0.2T and falls down along the radius to less than 0.01 T at 2 cm distance from the wall. This peripheral magnetic field increases the plasma density at the plasma grid by approximately 2 times reflecting a plasma from the wall and at the same time improves the uniformity of plasma flow at the ion emitter plane.

2.3 Hollow Cathode with internal LaB_6 emitter

Lanthanum hexaboride has a high emission electron current up to 20-40 A/cm^2 at rather moderate temperatures. We have introduced a LaB_6 electron emitter into the hollow cathode to increase efficiency of plasma production. The LaB_6 disk has 30 mm in diameter and 3 mm thickness. The LaB_6 tablet is supported by graphite rings and is heated by radiation of a wound tungsten wire. The discharge is initiated by applying a 20-50 V voltage between the tablet and the body of hollow cathode.

3. EXPERIMENTAL RESULTS

The discharge current was varied from 80 to 350 A. Fig. 2 shows the discharge voltage-current characteristic. The dependence was measured with 750 Gs longitudinal magnetic field near anode opening. The discharge current ~270 A was enough to extract 2 A ion beam.

The typical value of the heating power of the tablet was 650 W. The temperature of LaB_6 tablet was measured by an optical pyrometer. The temperature required for stable operation was found to be about 1700^0 C. At the same time, it was observed that due to the tablet extra heating during the discharge really 1450^0 C initial temperature was enough. The transition time from initial temperature to a steady-state was measured to be up to 0.2 s.

The radial profile of the plasma flow density measured at the plane of the first (plasma) grid is shown in Fig.3. The required non uniformity of ±10% was obtained inside a circle with diameter of 68mm, which enables to extract the beam with this diameter.

As it was already mentioned, the lifetime is a critical parameter for the arc-discharge plasma source. By now, about 1000 shots were made with pulse duration 1 s without noticeable damages to the source components. Several 2 s shots also were also made without critical damages to the source.

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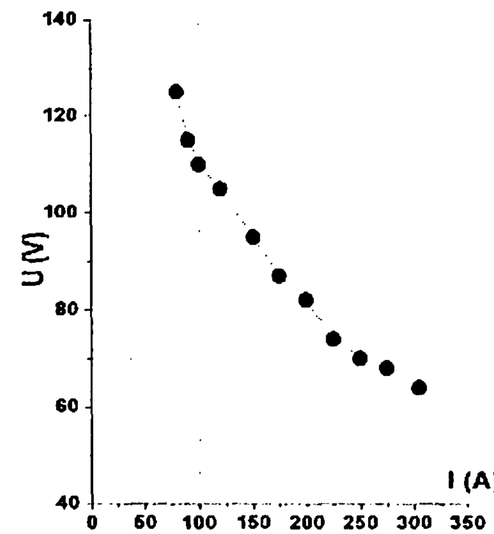

Fig. 2. Discharge voltage-current characteristic .

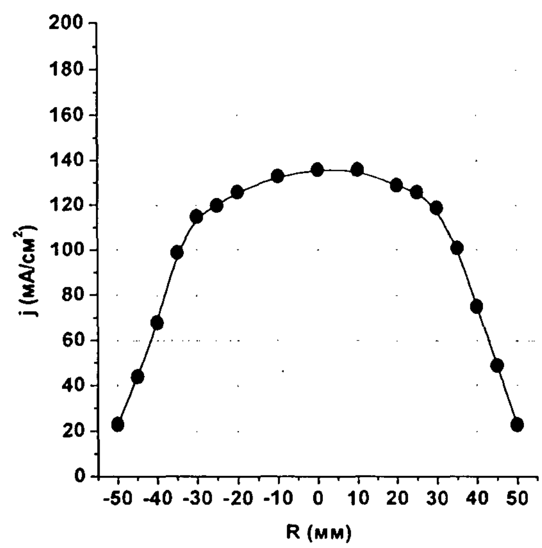

Fig.3. Radial profile of the plasma flow density.

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